



# Compression gain of spin wave signals in a magnonic YIG waveguide with thermal non-uniformity

O. Kolokoltsev<sup>a,\*</sup>, Ivan Gómez-Arista<sup>a</sup>, N. Qureshi<sup>a</sup>, A. Acevedo<sup>a</sup>,  
César L. Ordóñez-Romero<sup>b</sup>, A. Grishin<sup>c</sup>

<sup>a</sup> Centro de Ciencias Aplicadas y Desarrollo Tecnológico, Universidad Nacional Autónoma de México, CU 04510 D.F., Mexico

<sup>b</sup> Instituto de Física, Universidad Nacional Autónoma de México, CU 04510 D.F., Mexico

<sup>c</sup> Condensed Matter Physics, Royal Institute of Technology, SE-164 40 Stockholm, Kista, Sweden

## ARTICLE INFO

### Article history:

Received 10 September 2014

Received in revised form

30 September 2014

Accepted 1 October 2014

### Keywords:

Magnonics

Pulse compression

Spin wave

YIG

## ABSTRACT

We report on the observation of the compression gain of the signals carried by surface spin waves (MSSWs) in yttrium iron garnet films as a result of non-uniform optical heating of the spin wave medium. Efficient gain takes place if a frequency downshift of the spin wave spectrum induced by the heating is compensated by the corresponding non-uniformity of the bias magnetic field. It is proposed that the effect can be understood in part as an interaction between spin waves and a thermally induced potential well in the sample.

© 2014 Published by Elsevier B.V.

## 1. Introduction

Long wavelength spin waves in ferromagnetic solids, magneto-static waves (MSW), have been used in many kinds of analog microwave signal processors over the decades [1]. These collective excitations are very attractive due to the simplicity of the techniques used to generate them, the flexibility in available methods for their control, and a rich variety of linear and nonlinear properties. In recent years, there has been significant progress in spin wave technology applied to digital processing, for example in a spin-wave bus [2] and spin wave logic devices [3]. Since these elements are complex multi-cascade systems, an important problem is the compensation of propagation losses [4]. Spin-wave amplification using electrical currents has been studied in detail for ferromagnetic semiconductors and metals [5]. For ferrite dielectrics, an experimentally proven method is the parametric amplification of MSWs and their envelopes by a microwave pump [4,6]. An interesting approach to device miniaturization is the recently proposed parametrical amplification based on elastic stress modulation in ferrites [7]. These methods provide amplification in a relatively narrow microwave frequency band because they rely on resonant interactions. On the other hand, there are advantages to a solution that eliminates the need for additional microwave sources. It has been shown, for example, that in a Pt/Ferrite thin

film structure the amplitude of MSWs can be incremented through a transverse temperature gradient [8], or a voltage driven spin current [9]. These results, as well as recent reports on thermal control of a ferromagnetic resonance (FMR) linewidth [10,11], involve the spin torque transfer effect at a Pt/Ferrite interface.

In this work we report on the observation of the so-called compression gain in short pulses of magnetostatic surface spin waves (MSSW) obtained by concentrating the pulse energy near a potential well created in a magnonic waveguide by local optical heating. The pulse compression under time varying magnetic fields was discussed in earlier works [12,13]. In a number of recent publications it has been shown that static magnetic inhomogeneity modifies the dispersion characteristics spin waves [14–16], their modal distributions [17–19]. Resonant back and forward scattering of spin waves by a controllable magnetic defect has been demonstrated and studied in [20–22]. In most works magnetic inhomogeneity has been created by external magnetic field. Here, we describe the case of thermal control of the magnetization profile that leads to significant improvement of characteristics of a spin wave functional element. It should be noted, for the first time the possibility to control MSSW by flash discharge lamp has been shown in [23].

\* Corresponding author.

## 2. Experimental set-up

As the spin wave medium we used a 7.7  $\mu\text{m}$ -thick gallium-substituted yttrium iron garnet film (YIG) with saturation magnetization  $M_S \approx 77$  G, grown on a gadolinium gallium garnet (GGG) substrate with (111)-orientation. In our experiments we used an Ar-ion laser to heat the sample by using that fact that YIG strongly absorbs visible light. A schematic view of the experimental set-up is shown in Fig. (1). The YIG/GGG sample used was  $w=1$  mm wide in the Z direction and 20 mm long in the Y direction. The pulses of MSSW were excited at one end ( $Y=Y_0$ ) of the magnetically saturated sample by pulses of an electric current of approximately 50 mA, flowing through the 0.25 mm-wide microstrip line antenna terminated to a 50  $\Omega$  resistive load. In practice, the excitation pulses had a duration of 3 ns and their repetition period was 0.35–10  $\mu\text{s}$ . This method provides excitation of very short spin wave packets, with a duration of  $\tau \approx 10$ –20 ns. The largest allowable wavenumber ( $k$ ) is limited by the microstrip width  $k \approx \pi/w$ .

With pulsed excitation, the shortest period of the magnetization precession in the excited wave packet is limited by the rise time of the electric current pulse [24]. Since in our case it was 1 ns, the frequency band of the MSSW was centered slightly below 1 GHz, by an appropriate applied in-plane bias magnetic field  $H_0$  (Fig. 1). The bandwidth of the spin wave pulse was approximately 0.1 GHz, and its lower frequency ( $\omega$ ) is determined both by  $H_0$ , and  $M_S$ , so that  $\omega \geq (\omega_H (\omega_H + \omega_M))^{1/2}$ , where  $\omega_H = \gamma H_0$ ,  $\omega_M = 4\pi\gamma M_S$  and  $\gamma = 2.8$  MHz/Oe is the gyromagnetic constant.

The propagation characteristics of a spin wave pulse were observed using an inductive loop probe connected to a fast oscilloscope, sensitive to the microwave field induced by the spin wave at the surface of the YIG film [25]. The probe loop diameter was  $\approx 300$   $\mu\text{m}$ . It was fabricated from a 50  $\mu\text{m}$ -thick gold wire. The probe was scanned over the sample by motorized translation stages (Fig. 1). Local heating of the sample was realized by focusing an Ar-ion laser beam on the sample with controlled power ( $P_{\text{opt}}$ ), through the polished surface of the GGG substrate. This optical heater allowed us to change the sample temperature from 300 K to 416 K, by varying  $P_{\text{opt}}$  from 40 to 420 mW. The optical spot was 0.5 mm in diameter and was located at a distance of  $Y_L$  from the excitation port.

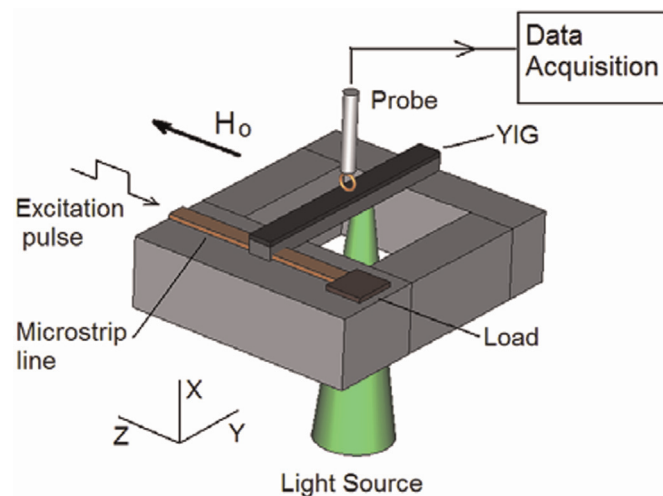


Fig. 1. Schematic view of the experimental geometry.

## 3. Results

With a uniform external field  $H_0=70$  Oe, and the laser spot at position  $Y_L=13$  mm, the temporal profile of the pulse was recorded with the probe at different positions on the sample. The evolution of the wave packet (measured by the instantaneous voltage) as it propagates along the sample at different values of  $P_{\text{opt}}$  is shown in Fig. 2a–d. We observe that the wave packet in the optically heated sample suffers a delay compared to the sample at room temperature (which we call the RT sample). As seen in the figure, the heating induces a nonuniform pulse delay that apparently correlates with the longitudinal profile of the sample temperature (or the position of the laser spot). This behavior is determined by a change in the spin wave dispersion relation, [4] and reflects the well-known decrease of the saturation magnetization  $M_S$ , as the ferrite temperature increases.

Under the same conditions, a representation of the spatial evolution of the pulse envelope is shown in Fig. 3a–d. The value of each point on the profiles in Fig. 3 is the amplitude of the spin wave envelope averaged over a time window ( $t_w$ ) of 30 ns. The data from the RT sample and a sample heated at  $Y_L=13$  mm are combined side-by-side in the same plots for comparison. We observe a pronounced increase in pulse amplitude in the vicinity of the laser spot.

The amplitude of the pulse profile is strongly influenced by laser power. Fig. 4 summarizes the amplitudes of the pulse envelope vs. the probe position at different values of  $P_{\text{opt}}$ . Here, the value of each point is the envelope amplitude averaged over  $t_w$  and over the sample width. We see that in the room temperature sample the pulse propagates and attenuates in the usual way, whereas with optical heating the pulse amplitude increases as it approaches the laser spot.

## 4. Discussion

The results indicate the existence of two related phenomena: an induced spatially non-uniform pulse delay, and a localized signal amplitude gain ( $G = A^{\text{hot}}/A^{\text{RT}}$ ). The nature of the induced pulse delay can be understood in terms of changes in the dispersion relation  $\omega(k)$ , [4] illustrated in Fig. 5. In the region with higher temperature, where  $M_S^{\text{hot}} < M_S^{\text{RT}}$ ,  $\omega(k)$  is downshifted in frequency with respect to  $\omega(k)$  of the room temperature region. Hence, the range of allowed wave numbers  $k_{\text{max}}-k_{\text{min}}$  in the pulse excited in the room temperature sample region will be up-shifted as the pulse enters the hot sample region. As a result, the group velocity  $v_g = \partial\omega/\partial k$ , or slope of  $\omega(k)$ , decreases in the hot region. It is known that the lifetime of dipole spin waves practically does not depend on  $k$ . Hence, decreasing  $v_g$  when the delay is spatially uniform should lead to stronger wave attenuation along the propagation path. Also, we would expect the up-shift of the wave numbers to increase MSSW losses because of the Y-dependent change in the wave impedance. However, the results in Fig. 3(a, b) and 4 indicate that the propagation losses are compensated near the heated zone.

Simple considerations suggest that the effect of the induced losses associated with the frequency downshift of  $\omega(k)$  in the region with higher temperature can be minimized or compensated. As shown in Fig. 5, by increasing the applied field  $H$ , the down-shifted  $\omega(k)$  in the hot region (curve 2a), can be up-shifted to the curve 2b. Therefore, the induced losses can in principle be minimized if  $H$  increases along the wave propagation path (or  $\partial H/\partial Y > 0$ ). In the opposite case (curve 2c), when  $\partial H/\partial Y < 0$ , a decrease in  $H$  can be expected to increase losses.

This idea was investigated experimentally by applying a uniform field  $H_0=100$  Oe to the sample and adding to it a

Download English Version:

<https://daneshyari.com/en/article/8156116>

Download Persian Version:

<https://daneshyari.com/article/8156116>

[Daneshyari.com](https://daneshyari.com)